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FTD-TT- 62-1757

TRANSLATION

METHODS OF MEASURING ROUGHNESS OF A WORKED SURFACE

By

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AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

FTD-TT- 62-1757/1+2

UNEDITED ROUGH DRAFT TRANSLATION

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English Pages: 17

SOURCE: Kratkiy Spravochnik Kontrol'nogo Mastera Mashinostroitel'nogo Zavoda, Chapter XI, Mashgiz, Moskva, Leningrad, 1961, pp. 206-218

PREPARED BY:

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WP-AFB, OHIO.

FTD-TT- 62-1757/1+2

Date 1 March 19 63

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CHAPTER XI

METHODS OF MEASURING ROUGHNESS OF A WORKED SURFACE

21. General Information on the Quality of a Surface

Up to the present time standards for the roughness of a worked surface have been laid down by GOST 2789-51. According to these standards, the roughness of a surface is classified by the mean height of the micro-irregularities (H_m) or else by the mean square deviation of the micro-irregularities (H_{ms}).

The mean height of the micro-irregularities (H_m) is defined as the arithmetic mean of the heights of the micro-irregularities from the crest to the bottom of the root of a 1 mm section (Fig. 95), i.e.,

$$H_m = \frac{H_1 + H_2 + H_3 + \ldots + H_n}{n},$$

where H is the height of individual irregularities from crest to root;

n is the number of heights measured.

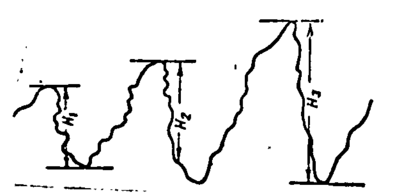

Fig. 95. Mean height of micro-irregularities H_m.

The mean square deviation of the micro-irregularities (H_{ms}) was defined as the square root of the mean square distance between points on the surface profile as far as the middle line, i.e., the line dividing the profile in such a way that the areas of both sides of it are equal up to the contour of the profile (Fig. 96), i.e.,

$$F_1 + F_2 + F_3 + \ldots + F_n = S_1 + S_2 + S_3 + \ldots + S_n,$$

$$H_{ms} = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \cdots + h_n^2}{n}}.$$

The middle line, which is taken as a kind of basis for measurement, can only be drawn with mathematical accuracy provided it intersects the profile in such a way that the sum of the squares of the distances between individual points on the profile up to the line is minimum. On a prophilograph, the middle line can be drawn with sufficient accuracy, for practical purposes, in such a way that the areas on both sides of it as far as the profile line are equal.

In this way, the middle line can be imagined as the microprofile of an ideally smooth surface which could be obtained if the material from the crest filled the root. All surfaces, beginning with the cleanest (after finishing operations) and ending with coarse surfaces (after roughing) were limited to fourteen classes of cleanliness.

For a finer gradation of the degrees of finish the standards permitted the division of classes into subclasses.

At the present time a new set of standards GOST 2789-59 has been published for the roughness of worked surfaces. A distinguishing feature of the standards is the introduction of new criteria for assessing the finish: the mean arithmetic deviation of the profile $\underline{R}_{\underline{a}}$ and the height of the micro-irregularities $\underline{R}_{\underline{z}}$.

The mean arithmetic deviation of the profile $\underline{R}_{\underline{a}}$ is defined as the mean distance between the points of the profile and the middle line over a given distance on the surface for which the roughness can be determined without taking into account the effect of other types of irregularities, such as undulation and error in shape.

The length of this section of the surface is called the base length. The base length $\underline{l}$ is selected in accordance with the type of machining and the roughness of the surface.

The height of the irregularities $\underline{R}_{\underline{z}}$ is defined as the mean distance

between the five highest projecting points within the base line and the five lowest points of the roots, measured from a line parallel to the middle line; this determines the measuring base for processing a prophilograph as well as for measuring the roughness of a worked surface by automatic devices.

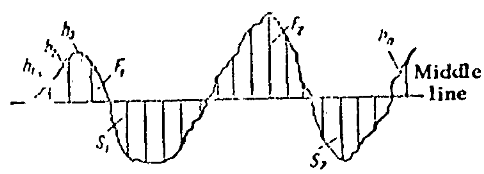

Fig. 96. Mean square deviation of micro-irregularities.

Under the standards GOST 2789-59 the height of the micro-irregularities R_z (just as the mean height of the micro-irregularities H_m under GOST 2789-51) does not describe the operational properties of the given surface, which depend not so much on the height of the irregularities as on their shape. So as to indicate the operational properties of the surface GOST 2789-59 contains the parameter R_a (whereas GOST 2789-51 contained H_{ms}).

According to GOST 2789-59, R_a is the basic parameter for the sixth to the twelfth class of finish inclusively, and R_z is for the first through fifth and thirteenth through fourteenth.

The new standards retain fourteen classes of surface finish. The sixth through fourteenth classes are further divided into subclasses (just as in GOST 2789-51).

Classes of worked surfaces according to GOST 2789-51 and 2789-59 are shown in Table 57, while the subclasses are shown in Table 58. As can be seen

from these tables, the numerical values for the classes 1 - 3 have been increased, and for classes 11 - 14 have been slightl; reduced, while for classes 4 - 10 there is no change.

Table 57

Table 57. Classes of finish of worked surfaces (under GOST 2789-51 and 2789-59)

Class of finish	Under GOST 2789-51: $\underline{H}_{ms}$ in microns	Under GOST 2789-51: $\underline{H}_m$ in microns	Under GOST 2789-59: $\underline{R}_a$ in microns	Under GOST 2789-59: $\underline{R}_b$ in microns	Under GOST 2789-59: Base-line 1 in mm
1	--	Over 125 to 200	80	320	
2	-	» 63 » 125	40	160	8
3	--	» 40 » 63	20	80	
4	--	Over 20 to 40	10	40	2,5
5	Over 3,2 to 6,3	» 10 » 20	5	20	
6	» 1,6 » 3,2	» 6,3 » 10	2,5	10	
7	» 0,8 » 1,6	» 3,2 » 6,3	1,25	6,3	0,8
8	» 0,4 » 0,3	» 1,6 » 3,2	0,63	3,2	
9	» 0,2 » 0,4	» 0,8 » 1,6	0,32	1,6	
10	» 0,1 » 0,2	» 0,5 » 0,3	0,16	0,3	0,25
11	» 0,05 » 0,1	» 0,25 » 0,5	0,[illegible]	0,4	
12	» 0,025 » 0,05	» 0,12 » 0,25	0,01	0,2	
13	--	» 0,06 » 0,12	0,02	0,1	0,08
14	--	to 0,06	0,01	0,05	

The greatest possible deviations are shown for $\underline{R}_a$ and $\underline{R}_z$.

Comparing the figures for $\underline{R}_a$ and $\underline{H}_{ms}$, we find the following relationship

$$\frac{H_{ms}}{R_a} \approx 1,25.$$

A distinghishing feature of the new GOST is that apart from defining the irregularities themselves, they also define the space between them. Whereas GOST 2789-51 used only to define the amplitude in oscillation of the micro-irregularities, the present GOST 2789-59 also determines the wavelength. It is for this purpose that the base line $\underline{l}$, which is the wavelength or pitch between irregularities, has been introduced.

For different baselines the numerical values of the irregularity height parameters of the same surface may vary by a factor of 2 - 4. For example, when measuring the same surface with respect to the parameter $\underline{R}_a$ with different base lines,

Table 58

Table 58. Classes of finish of worked surfaces (under GOST 2789-51 and 2789-59)

Class of finish	Sub-class	Under GOST 2789-51: $\underline{H}_{ms}$ in microns	Under GOST 2789-51: $\underline{H}_{m}$ in microns	Under GOST 2789-49: $\underline{R}_a$ in mic.	Under GOST 2789-49: $\underline{R}_z$ in mic.
6	a	Over 2,5 to 3,2	—	2,5	10
	b	» 2 » 2,5	—	2,0	8
	c	» 1,6 » 2	—	1,6	—
7	a	Over 1,25 to 1,6	—	1,25	6,3
	b	» 1 » 1,25	—	1,0	5,0
	c	» 0,8 » 1	—	0,8	4,0
8	a	Over 0,63 to 0,8	—	0,63	3,2
	b	» 0,5 » 0,63	—	0,5	2,5
	c	» 0,4 » 0,5	—	0,4	2,0
9	a	Over 0,32 to 0,4	—	0,32	1,6
	b	» 0,25 » 0,32	—	0,25	1,25
	c	» 0,2 » 0,25	—	0,20	1,0
10	a	Over 0,16 to 0,2	—	0,16	0,8
	b	» 0,125 » 0,16	—	0,125	0,63
	c	» 0,1 » 0,125	—	0,10	0,50
11	a	Over 0,08 to 0,1	—	0,08	0,4
	b	» 0,063 » 0,08	—	0,063	0,32
	c	» 0,05 » 0,063	—	0,05	0,25
12	a	Over 0,04 to 0,05	—	0,04	0,2
	b	» 0,032 » 0,04	—	0,032	0,16
	c	» 0,025 » 0,032	—	0,025	0,125
13	a	—	Over 0,1 to 0,12	0,02	0,1
	b	—	» 0,08 » 0,1	0,016	0,08
	c	—	» 0,06 » 0,08	0,012	0,063
14	a	—	Over 0,03 to 0,06	0,01	0,05
	b	—	До 0,03	0,008	0,04
	c	—	—	0,006	0,032

The greatest possible deviations have been taken for $\underline{R}_a$ and $\underline{R}_z$.

the following figures were obtained[2]: given base line $\underline{l}$ = 0.8, 0.25 and 0.08 mm, the values of $\underline{R}_{\underline{a}}$ were 3.9, 2.0 and 1.0 microns, respectively, i.e., as the base line was lengthened, the values of the same surface profile were increased.

This is due to the fact that as the base line is lengthened, a larger number of component micro-irregularities on the surface with different pitches are taken into account (Fig. 97).

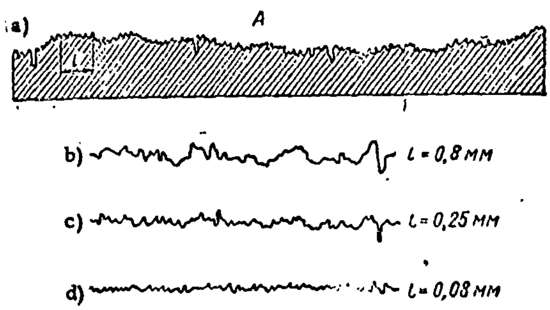

Fig. 97. The effect of baseline $\underline{l}$ on height of micro-irregularities: a) profile of surface $\underline{A}$; $\underline{b}$,$\underline{c}$,$\underline{d}$) prophilographs of surface $\underline{A}$ attained with different baselines.

GOST 2789-59 give the relationships between the baseline and the classes of roughness. Designers are in a position to use other baselines differing from those laid down by GOST. In this case the baseline is indicated in the specification for manufacture of the part, unit or assembly.

The relationship between classes of accuracy in the dimensions of parts and classes of finish of their surfaces is governed by the technique used to work the part. The more accurate the required dimensions of the part, the higher the class of surface finish. For example, calipers, working journals and spindles in precision lathes which have to be made in accordance with the first class of accuracy ARE WORKED with great precision and great cleanliness.

An approximate comparison of the classes of accuracy and classes of finish is shown in Table 59.

It is quite obvious that the roughness of a surface is linked with the accuracy with which the part is worked, but the link between size tolerance and the roughness of the worked surface has not yet been sufficiently thoroughly studied, hence there is no direct constructive link between classes of accuracy and surface finish at the present time.

GOST 2789-59 introduces new symbols for the roughness of the worked surface.

One sign has been fixed for designating all classes of surface roughness; it is an equilateral triangle alongside which is marked the number of the class or the number of the class and subclass, for example, $\nabla 6$, or $\nabla 7b$. Since in the new standards the numerical value of the surface roughness only improves the upper limit of roughness for the criteria R_a or R_z, in cases in which we are required to limit the maximum and minimum roughness at the same time, the symbol has to indicate two class or subclass numbers. For example, $\nabla 9 - 10$ means that the roughness according to R_a must not be less than 0.16 and not more than 0.32 microns. The symbol ∇ 9b-9c shows that R_a must not be less than 0.2 and not more than 0.25 microns.

Surface roughness coarser than the first class is shown under GOST 2789-59 by the tick $\checkmark$, above which is placed the height of the irregularities R_z in microns, for example, $\overset{500}{\checkmark}$. The numerical values of R_z are taken from the series R10 in GOST 8032-56 as: 400, 500, 630 and 800. Here the point of the tick must be at the same level as the line showing the surface or on a continuation of the line, while the bisector of the tick $\checkmark$ must be perpendicular to the line.[3]

The new standards GOST 2789-59 come into effect from January 1, 1962. But the new symbols for the roughness of the worked surface came into force on

October 1, 1959.

Table 59

Approximate comparison of classes of accuracy and classes of finish of worked surfaces for parts made of medium-hardness steel worked in different ways

Machining operation	Class of finish	Class of accur.
Fine turning; fine drawing	1	9
Finish turning; finish boring	2	8
Rough turning	1	5
Bottom reaming with precision-made fast-cutting reamers	2	7
Internal broaching	3	6--7
Drilling, counter-boring	4	4--5
Cylindrical and end milling; outside broaching	3	6--7
Shaving	2	8
Gear milling; gear shapping with class A gear shaper cutters	2--3	6--7
Gear hobbing with unpolished profile Rough gear shaping	4	5 - 6
Taping with polished profile	1--2	7--8
Thread milling with internal-contact disc cutters	3	6
Tapping with unpolished profile	4	5

22. WAYS AND MEANS OF MEASURING ROUGHNESS OF WORKED SURFACES

Methods of measuring the roughness of a worked surface divide up into qualitative and quantitative.

The quantitative method of inspecting the roughness of a worked surface is usually used at the work site for parts with a roughness not exceeding classes 7 and 8.

The method is based on comparison of the inspected surface with a set of metal bars with flat and cylindrical surfaces worked in different ways and under specific conditions.

Here the type of machining, the material and the shape of the surface of the standard must correspond to the type of machining, material and shape of the

surface of the part being inspected.

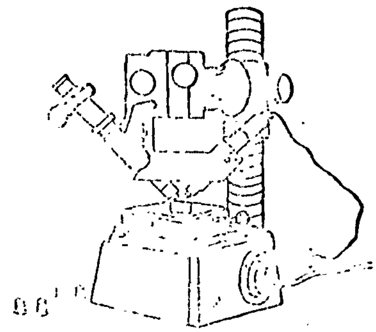

Fig. 98. Double Linnik microscope

The class of finish is determined (when the roughness of the surface and the standard are compared) by the visual-tactile method for surfaces with a roughness not exceeding class 6. For surfaces with a roughness between classes 7 and 10, the roughness is collated with the standard by means of a comparison microscope (MS-48; MS-49; MS-51). Both surfaces can be seen at the same time on a larger scale in the field of vision of a microscope of this kind.

For inspecting the roughness of a worked surface at points which are hard to get at and cannot be measured by means of instruments or standards of surface finish, the mold method is used. This method consists in taking casts of the surface being inspected. The imprinted microgeometry of the given area of surface is usually measured with a MIS-11 Linnik microscope (Fig. 98). A gutta percha mixture consisting (by weight) of 45% spindle tree gutta percha, 20% No. 5 bitumen, 34% S machine oil and 1% D anti-oxidant is used for taking the casts.

To make the cast the mixture is cut into pieces 10 - 15 g and heated up to 80 - 90° in a vessel containing water.

When it is hot, a piece of mixture is taken from the vessel and "reversed" in such a way that there is no film of water on it. Then it is pressed by hand against the surface being inspected (the hands are first damped with cold water and the surface in question is thoroughly cleaned with benzol). The thickness of the layer of mixture after application should not be less than 4 mm. It takes 15 to 25 minutes for the impression to cool. A gutta percha impression of the microgeometry of the surface remains intact for a long time. When carefully handled, the mixture can withstand numerous heatings and coolings. Its service life is from 1 to 1-1/2 years.

Estimation of the irregularities on the cast usually results in a figure lower than that obtained by direct measurement of the surface.

The relative error in measurement of the roughness as a function of the cast material ranges between 2 and 8%. In order to obtain the true roughness value, the figure obtained for the cast has to be multiplied by the correction coefficient, which in the case of a gutta percha mixture is 1.05.

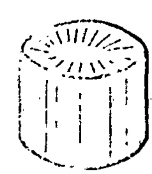

Fig. 99. Support for testing casts with MIS-11 microscope.

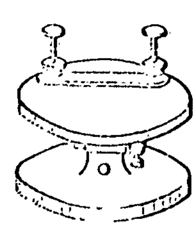

Fig. 100. Swivel Table

In view of the fact that the thickness of the cast varies, a great deal of time is wasted on placing it in position on the double microscope. It is suggested that when determining the roughness of a cast, the latter should be placed on a support with a spherical surface (Fig. 99). By moving the cast over the spherical surface we can keep the test surface of the cast parallel to the plane of the table very easily. A swivel stage holding the parts is used for similar purposes (Fig.100).

Estimation of the roughness of a worked surface by the quantitative method is made by special instruments. The appropriate instruments for inspecting the surface can be divided into contact (tactile) and non-contact (optic) types. The contact instruments utilize the principle of feeling the test surface by means of a needle probe[4]. The relative oscillation of the needle up and down due to the irregularity of the surface is recorded by a self-recording device which produces an enlarged microprofile of the surface in the form of a prophilograph. In this case the instrument is also called a prophilograph. But if the oscillation of the probing needle is transmitted in magnified form by a system of levers to a scale on the instruments showing readings for the roughness, the instrument is then called a prophilometer.

Non-contact measuring instruments are either based on the principle of the light cross-section of the tested surface (for example, the double MIS-11 Linnik microscope) or else on the use of interference (for example, the MII-4 Linnik interference microscope) in which the height of the micro-irregularities is described by the degree to which the interference bands bend at the sites of projections or cavities in the test surface. The extent to which the interference bands bend is determined in fractions of the band width by means of a screw-type ocular micrometer or by the eye.

The MIS-11 double linnik microscope (Fig. 90) is intended for inspecting roughness with respect to the parameter H_m for surfaces from the third to the ninth

class of surface finish (GOST 2789-51). Different objectives can be attached to the device in accordance with Table 60 for the inspection of various other classes of surface finish. When micro-objectives are used for other classes of finish not given in the table, the error in measurements is greatly increased.

Table 60

Set of micro-objectives for use with MIS-11

Symbol for objective	Total dist. of objective in mm	Magnification and aperture of objective	Gen. magnif. for 15-fold AM-9-2 eyepiece	Linear field of vision in mm for 15-fold AM-9-2 eyepiece	Purpose of objective: H_m in microns	Purpose of objective: Classes
OS-39	25,02	5,9× - 0,13	69×	1,73	6,3 - 63,0	3 - 6
OS-40	13,89	10,6× - 0,20	159×	0,9[illegible]	3,2 - 10,7	5 - 7
OS-41	8,16	[illegible]× - 0,37	[illegible]×	0,58	1,6 - 10,7	6 - 8
OS-42	4,25	[illegible]× - 0,50	518×	0,30	0,8 - 3,2	8 - 9

The maximum size of parts which can be inspected with a MIS-11 is 100 mm; for parts of greater dimensions the Leningrad Kirovskiy Plant uses the base of a large instrument microscope (BIM) plus the optical system of the MIS-11.

When inspecting both cylindrical and flat parts directly at the place of work, this plant also uses a special prism which is attached to the double microscope (Fig. 101). Linnik interference microscopes (Fig. 102) are used to inspect surfaces with a roughness between the 10th and 14th classes of finish in terms of H_m.

To measure the micro-irregularities with an MII-4 we have to determine the bend a in the interference band in fractions of the interval between bands b and multiply the result by 0.275 microns.

Of the non-contact devices mentioned above, the MIS-11 Linnik double microscope is intended for measuring the finish of worked surfaces from the 3rd through 9th classes; the MII-1, MII-4 and MII-5 interference microscopes are used

for surfaces from the 10th through 14th classes.

To determine roughness in terms of H_{ms}, use is made of the KV-7 electrodynamic prophilometer and the PCh-2 and PCh-3 induction prophilometers.

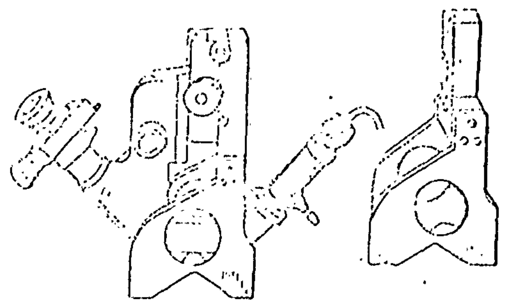

Fig. 101. Prisms for use with MIS-11 microscope

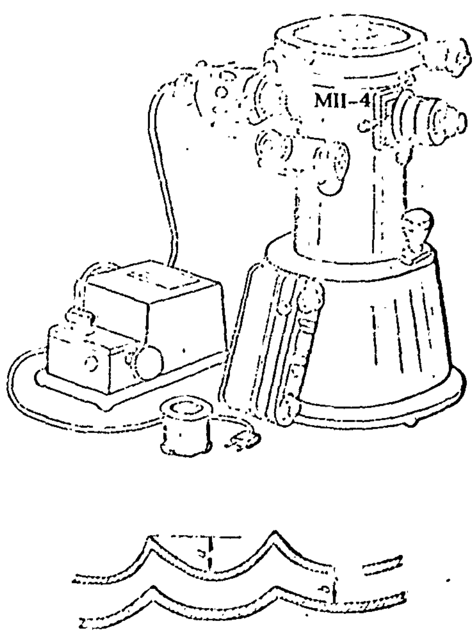

Fig. 102. Linnik interference microscope.

The KV-7 and PCh-3 prophilometers consist of an amplifier with an indicating device mounted in the prophilometer casing, and a data unit with replaceable supports and needles. The PCh-3 prophilometer is shown in Fig. 103.

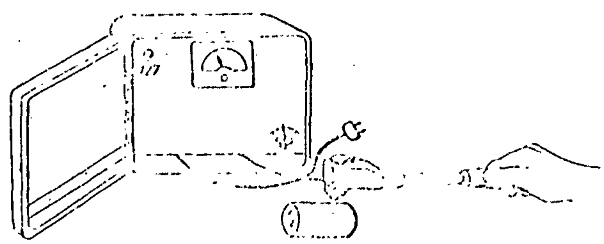

Fig. 103. PCh-3 phophilometer.

The operational characteristics of the basic instruments used to measure the roughness of worked surfaces are given in Table 61.

With the coming into effect of the new state standards GOST 2789-59 it will only be possible to use these instruments to a limited extent. The measurements will be processed by means of special conversion tables.

Table 61

Operational characteristics of devices for measuring surface roughness

A. Tactile devices (prophilometers and prophilographs) determining $R_a(H_{ms})$ for classes 5 to 12

Type of instrument	Size and weight	Basing and reading system	Error in reading in %	Nominal radius of rounding of needle	Amp. of probing P in Gcm referred to 11-12 cl. & stat. amp. grad. k in Gcm/new	Path length in mm	Length of measured path in mm	Great. pitch btwn. regul. taking into acct. when meas. with device B_{max} in mm	Probing rate in mm/sec	Least test dia. of internal orifice in mm
KV-7 electrodynamic prophilometer	Prophilometer 500 x 280 x 210 mm; 11.5 kG. Motor dr. 200x130x720 mm; 6kG.		15	10±2	$P = 0,4-0,6$ $k = 0,1$	~2	Fr. 1-40 (motor dr) & more than 40 when data unit is moved by hand	0.3 for motor dr. and 0.75-0.8 for manual shift of data unit	5,5–6,5	From 6 or more
PCh-3 induction prophilometer	275x275x 145 mm; 6.5 kG	Supports based on test surface	25		$P = 0,2-0,3$ $k = 0,04-0,05$	2,5	From 1.5 or more	0,75–0,8	12–15	From 30 or more
Electrodynamic prophilometer made by Abbot, Mod. PAC (USA)	Prophil. 540x 190x270 mm; 14 kG. Motor dr. 220x120x 120 mm; 6 kG		15	12,5	$P = 0,8-1$ $k = 0,2$	~1,8	Fr. 0.5-100 (motor dr.) or more than 100 with man. shift	0.3 for motor dr. & 0.75 for manual shift	6–6,5	Fr. 3 or more
Forster Inst. prophil.-prophilogr. Mod. 5810 (GDR)	290×250×160 мм; 7,5 kg; $V_v = 30 - 10\,000\times$; $V_g = 20 - 200\times$	Straight sup. based on test surface	—	10	$P = 0,1$	10	Constant 10	—	1	From 3 or more
Kalibr-VEI induction prophilogr.-prophilometer	1450×720×1600 мм; 300 kg; $V_v = 2000 - 120\,000\times$; $V_g = 12 - 432\times$	Supports rest. on test surface	10	2 и 10	$P = 0,1$ $k = 0,001$	2,5–3	Const. 2.5-3 (prophilometer) and up to 8 (prophilogr.)	0,6	0.46 (prophilomtr.) 0.21-0.84 (prophilogr.)	Fr. 9 or more

B. Optical-mechanical devices determining R_z (H_m)

Type of device	Loss of surface roughness	Technical data
Linnik MIS-11 double microscope	$3-9H_{ms}$ $6-9R_z$	Greatest enlargement 518x; 4 paris of objectives; coordinating stage and photo attach.
MII-1 interference microscope	10–14	Uses monochromatic and white light; has coordinating stage and camera
MII-5 interference microscope (simplified model)	10–14	Only works in white light; no coordinating stage or camera
MI-4 interference microscope (new model)	10–14	Uses white light and light filters; has coordinating stage and special camera
Comparison microscope MS-51	7–10	Over-all magnification 70 x; wt. 200 g; dimensions 30 x 210 x 40 mm

Footnotes

1. Under GOST 2789-51 the main index for the 5th through 12th classes was H_{ms}, and H_m for the 1st through 4th and 13th through 14th classes.

2. According to data from Institute of Machine Building of AS of USSR.

3. More detailed instructions on the shape and size of the tick ✓ are given in the additional comments to GOST 2940-52.

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